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AMMRC CTR 77-27

# GLASS/PLASTIC TRANSPARENT ARMOR FOR THE UH-1 HELICOPTER

October 1977

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Final Report Contract Number DAAG 46-76-C-0070

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Prepared for  
ARMY MATERIALS AND MECHANICS RESEARCH CENTER  
Watertown, Massachusetts 02172

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AMMRC CTR 77-27	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) GLASS/PLASTIC TRANSPARENT ARMOR FOR UH-1 HELICOPTER		5. TYPE OF REPORT & PERIOD COVERED Final - Oct. 1976- July 1977
		6. PERFORMING ORG. REPORT NUMBER GERA-2274
7. AUTHOR(s) Wilson C. McDonald		8. CONTRACT OR GRANT NUMBER(s) DAAG46-76-C-0070
9. PERFORMING ORGANIZATION NAME AND ADDRESS Goodyear Aerospace Corporation Arizona Division Litchfield Park, Arizona 85340		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS D/A Project: 1T163102D071 AMCMS Code: 613102.12.159 Agency Accession: DA OF 4777
11. CONTROLLING OFFICE NAME AND ADDRESS Army Materials and Mechanics Research Center Watertown, Massachusetts 02172		12. REPORT DATE October 1977
		13. NUMBER OF PAGES 51
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Aircraft armor                      Glass Transparent armor                  Cast-in-place interlayer Glass/Plastic laminates          Polycarbonate Ballistic protection               Abrasion resistant coating		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  The program is a continuation of the armor work previously conducted on Contract DAAG46-73-C-0075, which for the first time incorporated significant amounts of high-performance glass/plastic laminated armor in an aircraft. During this earlier program, certain deficiencies in materials and processing were identified which required additional work to resolve.		

## 20. Abstract (continued)

This new effort has attempted to solve these problems while scaling up to a higher threat level. The program was divided into two phases. The first phase included the fabrication of three **shipsets** of scaled-up, full-size UH-1 windshields. Phase II includes the installation of two sets of windshields on test aircraft at two separate locations in the United States.

## FOREWORD

This is the final technical report on a two-part program which included the fabrication of three shipsets of UH-1 glass/plastic transparent armor, and the installation of two shipsets in aircraft at two separate Army facilities where they were flight tested.

The program was conducted at Goodyear Aerospace Corporation, Arizona Division, Litchfield Park, Arizona, under Contract Number DAAG46-76-c-0070.

This work was done for the Army Materials and Mechanics Research Center, Watertown, Massachusetts, under Project Number 1T163102D07 1.

The **Technical Supervisor** for this contract is Mr. Gordon R. Parsons.

Wilson C. McDonald is Project Engineer for Goodyear Aerospace Corporation. This report covers work conducted between October 1976 and July 1977.

Goodyear Aerospace Corporation has assigned GERA-2274 as a secondary number to this report.



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## SUMMARY

This report covers a program which entailed the fabrication of three **shipsets** of UH-1 transparent armored windshields as well as **inflight** evaluation of two of these shipsets. The work incorporated the latest advances in processing **high-**performance glass/plastic composite transparent armor. The primary emphasis was placed on the design and scale-up to increase the ballistic protection level over that produced on previous programs and to improve processing which would lead to more uniformity from part **to** part and **would** reduce overall cost. The design of the armored windshields permitted a direct replacement and added a significant level of protection with very little aircraft modification. The program was divided into two phases. Phase I included the design, fabrication, and optical evaluation of three **shipsets** of windshields. Phase II covered the shipment and installation of two sets of the armored windshields, one of which was delivered to Ft. **Rucker**, Alabama; and the other to Yuma Proving Grounds, Yuma, Arizona, for flight test evaluation.

## SECTION 1

### INTRODUCTION

#### 1. GENERAL

This program was a continuation of the effort beyond the scope of previous contract DAAG46-73-C-0075.

Work on the previous armor contract resulted in the installation of lightweight transparent armored windshields in a flight test aircraft. The concept and design were well accepted by Army personnel conducting the flight testing. It was demonstrated that both contoured and flat transparent armored panels which offer good optical quality and considerable projectile and fragment defeat capability could be installed on Army helicopters. The UH-1 armor installation increased the overall survivability of the aircraft by protecting both the aircrew and vital aircraft components. This achievement clearly represented a milestone in aircrew and aircraft protection.

Certain deficiencies in material and processing were identified in the previous program which required additional work. This report covers the new work authorized on Contract DAAG46-76-C-0070.

#### 2. PROGRAM SCOPE AND OBJECTIVES

The work accomplished and reported herein was directed toward demonstrating the practicability of incorporating improved higher threat level transparent armor in current inventory and new helicopters still in the design or prototype stages.

The UH- 1 transparent armored windshields produced demonstrated manufacturing capability of a scaled-up higher threat level composite than produced on the prior contract.

Revised processing, including improved glass forming techniques, were used to produce improved part-to-part uniformity.

Several of the armor composites included a newly-developed cast-in-place (CIP) urethane interlayer in an effort to alleviate the opacity problem and polyvinyl butyral (PVB) bubbling experienced on previous constructions.

One set of windshields was delivered to Ft. Rucker, Alabama, and one set to the U. S. Army Proving Ground, Laguna Field, Yuma, Arizona, for flight test evaluation.

Preliminary environmental testing conducted by Goodyear Aerospace indicated the composite selected should meet all military requirements.

## SECTION 2

### TECHNICAL APPROACH

#### 1. GENERAL DESCRIPTION

Contract **DAAG46-76-C-0070** was initiated to show that the problems which became evident as the result of the previous program could be overcome through revised processing and use of improved materials. In addition, it was a primary aim of the contract to produce a higher threat level transparent armor than had been produced on the prior contract and to demonstrate that the state-of-the-art will permit the incorporation of transparent armor in current inventory or **next-generation** aircraft.

#### 2. PHASE I - TRANSPARENT ARMOR DESIGN, FABRICATION, AND OPTICAL TESTING

##### a. Fabrication and Construction

Phase I work included the fabrication of three sets of full-scale, curved glass/plastic windshields which conform to the window contour of the UH-1 helicopter.

The construction of the transparent armor windshield was as follows:

- 0.375-in. -thick soda-lime annealed plate glass
- 0.060-in. -thick Goodyear Aerospace **F4X-1** silicone interlayer
- 0.375-in. -thick soda-lime annealed plate glass
- 0.100-in. -thick Goodyear Aerospace polyurethane interlayer code **361**
- 0.187-in. -thick polycarbonate 9030-112 grade  
(WA stabilized) with Goodyear Aerospace abrasion-resistant coating.

b. Environmental Test Data

Prior to start of work on this contract, Goodyear Aerospace had completed an environmental testing program to assure reliability. The test results were submitted to the Army in report number CLA-4226.

c. Refined Glass Forming Procedure

New processing recently developed was used to produce glass to the shape required for the UH-1 windshields. Primary emphasis was placed on producing improved part-to-part reproducibility of contour. This factor significantly influences the optical and environmental stamina of the transparent armor as well as the manufacturing economy. The excessive variation of contours in the glass components of the windshields produced on the previous contract created many fabrication problems. These variations necessitated the use of costly individualized sets of matched tooling to produce the armor. While such action allowed the manufacture of reasonably good-quality parts, the optimization of the optical and environmental properties for such articles required better control of the basic glass contour.

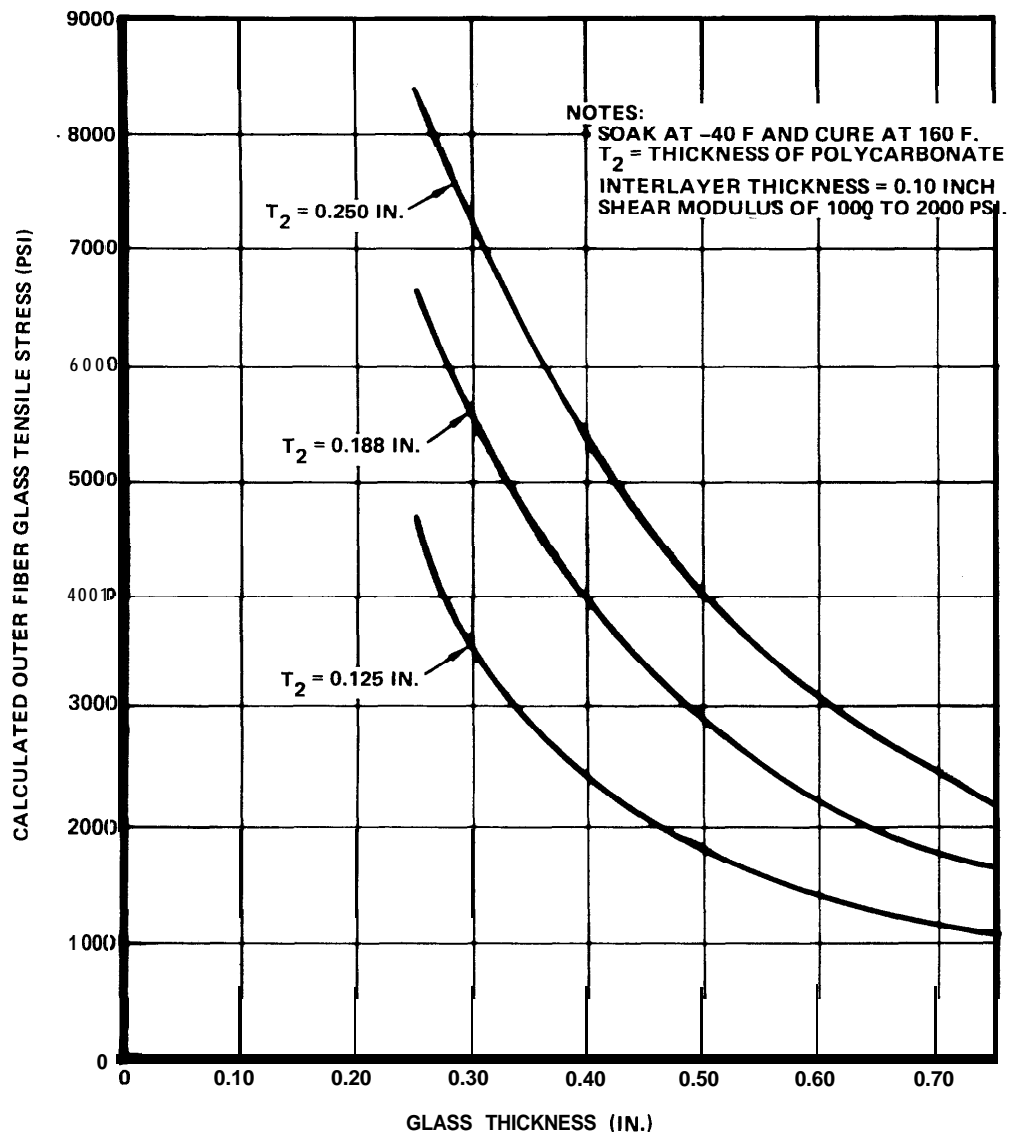
d. Interlayer Improvement Evaluation

The transparent armor produced on the previous contract utilized Goodyear Aerospace Code F4X-1 silicone CIP interlayer. The two factors that established the choice of the F4X-1 interlayer were its use in the transparent armor for lower threat levels where an extremely low-modulus interlayer is necessary to prevent breakage of the thinner glass faces, and the long pot life of the silicone interlayers which permitted injecting the resin into the casting cell at relatively low pressures over a considerable period of time. Polyurethane interlayers recently developed, and the 361 formulation in particular, have short pot life time but can be dispensed from an automatic mixing machine, making them practical for assemblies such as the UH-1 windshield.

e. Design Analysis Approach

The application of the polyurethane interlayer systems to transparent armor applications requires careful design analysis and close temperature control in fabrication. The basic problem is breakage of the glass faces from stress induced by thermal strains of the composite. It is only with the advent of the high-performance transparent armor that the glass faces become thick enough to resist the **flexural** stresses induced. Even this is not an absolute solution, however, since the shear forces increase and it is possible for the interlayer to fail the glass in horizontal shear. The problem is further complicated by the uncertainty of allowable stress on glass when subjected to long-term loads. The design analysis therefore becomes a combination of mathematical analysis, empirical analysis, and proof testing with a final solution potentially refined by trial and error in tests. The advantages of the polyurethane systems over the silicone systems appear to make the effort to solve these problems worthwhile when the composite has a cross section configuration that makes it a practical approach.

The results of the mathematical analysis can be examined from the curves of Figure 1. These curves were plotted from results of computer runs and show how the calculated glass outer fiber tensile stress will vary with thickness of the glass face for three different thicknesses of polycarbonate faces denoted by  $T_2$ . This plot examines the case of one particular polyurethane interlayer system that cures at a temperature of 160 F and has a shear modulus between 1000 and 2000 psi at the lower temperatures (about 1600 psi at -65 F). For



**Figure 1.** Calculated Stress from Thermal Strain

interlayers in this modulus range, the maximum glass tensile stress is not affected by the change in modulus. However, the shear stress is. The calculated shear stress for each shear modulus ( $G_1$ ) is:

<u>T<sub>2</sub> (in. )</u>	<u>G<sub>1</sub></u>	<u>Shear Stress</u>
0.125	1000	122
0.125	2000	174
0.188	1000	150
0.188	2000	212
0.250	1000	172
0.250	2000	244

Since the tensile stiffness factors (thickness  $\times$  tensile modulus) of the glass is much greater than that of polycarbonate in all cases, the shear stress does not change with changes of glass thickness in the range being studied

Goodyear Aerospace% experience has been that the glass probably will not fail in tension if the glass stress is less than 2000 psi and probably will not fail in horizontal shear if the glass stress is less than 350 psi. Since the curves of Figure 1 are for a 36-inch length, and the maximum tensile stresses are in the center of the panel, the allowable value for a 36-inch-square panel should be reduced to a value of about 1500 psi.

Conclusions, then, are:

1. A panel with polycarbonate thickness of 0.125 in. and glass face thickness of 0.575 in. or greater probably will not fail the face sheet in tension at -40 deg F. All other factors, including thinner glass, thicker polycarbonate, or a combination of these, will create the probability of failure

2. The shear stress is sufficiently below the expected failure level of 350 psi to be safe. This would permit a slight decrease in the interlayer thickness which would result in a decrease of glass tensile stress and an increase of shear stress
3. Since all these stresses are directly proportional to temperature change, a system that cures at less than 160 deg F would have decreased stresses. For instance, if the cure temperature is reduced to 130 F, the stresses at a -40 F would decrease by 85 percent
4. Another implication of the temperature effect is that a panel can be made safe by limiting the low temperature. For instance, a panel with 0.125-in. polycarbonate and ~~0.400-in.~~ glass (0.125-in. ply laminated to a ~~0.250-in.~~ ply) would be safe so long as it was never exposed to a temperature below ~~+40~~ F
5. The system studied is marginal for applications to -40 deg F, but an acceptable cross section configuration can probably be established
6. Goodyear Aerospace is continuing research and development effort in composite design and will make the data generated available to AMMRC.

### 3. ENVIRONMENTAL TESTING

#### a. General

Prior to the start of work on the contract, Goodyear Aerospace agreed to complete certain environmental testing already underway and to report the test results to AMMRC.

These tests, covering high temperature, low temperature, temperature shock, humidity, and ultraviolet (UV) stabilization, were selected because they represent the most severe conditions proposed by established military specifications. Although some of these tests may not represent actual environmental conditions of helicopter glazings, every attempt was made during the testing program to comply with the true intent of the specification.

Two sets of 36- × 36-inch panels were prepared. Each set consisted of one panel of each construction shown in Figure 2. One set was exposed to the humidity test and the other set to high temperature, low temperature, and temperature shock. Smaller panels, 12 × 12 inches, with urethane interlayer in both bond lines, were exposed to UV and outdoor weathering tests. Previous test data is available for silicone interlayers exposed to UV and outdoor weathering to confirm that no degradation is experienced under these conditions.

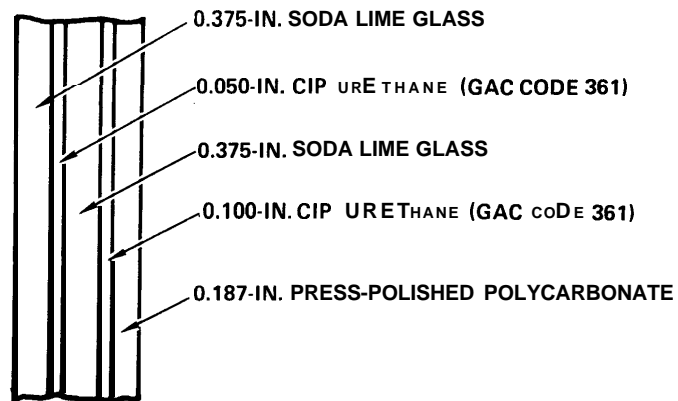
It should also be noted that the humidity test was performed in accordance with Procedure 1 of MIL-STD-810C, Method 507, which is more severe than the Procedure 5 specified in the contract.

b. High-Temperature Testing

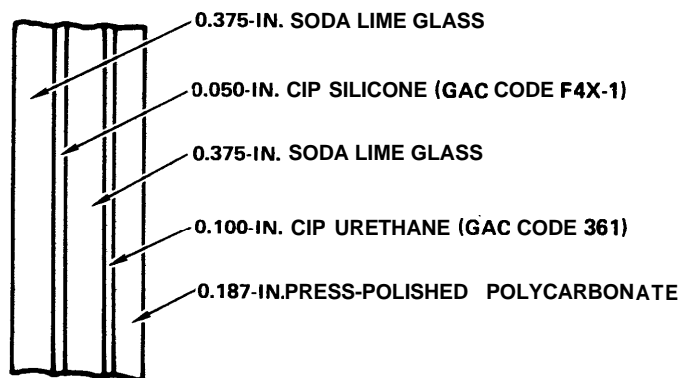
Several panels during the test program were subjected to high-temperature testing as outlined in MIL-STD-810C, Method 501, Procedure 1.

This test calls for the item to be placed in a test chamber in which the temperature is raised slowly (18 deg F per minute or less) to 160 deg F. This temperature is maintained for 48 hours. The test chamber temperature is then lowered slowly to ambient and stabilized.

The panels subjected to this test repeatedly passed with no evidence of cracking, clouding, delamination, or other visible signs of degradation.



CONSTRUCTION NO. 1



CONSTRUCTION NO. 2

Figure 2. Test Panel Constructions - 36 X 36 Inches

Since the armor composites are cured during manufacture at or near 160 deg F, no degradation was expected during this test.

c. Low-Temperature Testing

The panels were tested in accordance with MIL-STD-810C, Method 502, Procedure 1.

Low-temperature testing calls for the test item to be placed in a chamber and the temperature lowered at a rate not exceeding 18 deg F per minute until -70 deg F is reached. (Goodyear Aerospace and AMMRC subsequently agreed to -40 deg F as a more desirable temperature for glass/plastic armor panels.)

The low temperature is maintained for a period of 24 hours. The panel is then returned to ambient temperature and examined.

Goodyear Aerospace Construction No. 1 and Construction No. 2 successfully passed this test at three different low-temperature levels: -20 F, -30 F, and -40 F.

Because previous testing has shown that glass breakage can occur at low temperatures, every precaution was taken to ensure success. All glass edges were hand dressed to eliminate chipped areas and to provide a smooth, stress-free glass. The temperature was lowered slowly over a three-hour period to -20 F and held overnight to determine the effect of this temperature on the composite. A window in the test chamber permitted periodic inspections, and no degradation was evident. The second day, the temperature was lowered to -30 F and held for 5 hours. Again, inspection revealed that the panels were undamaged.

The temperature was then lowered to -40 F and held overnight. The panel was then returned to ambient over a period of several hours and removed from the chamber. The two panels showed no evidence of any deterioration.

Light transmission and haze were checked before and after completion of the tests. The results are shown in Table 1.

TABLE 1. LOW-TEMPERATURE TEST DATA

	Before test	After test
Light transmission average (percent)	72.2	72.5
Haze average (percent)	1.0	1.0

d. Humidity Testing

One panel of each construction (No. 1 and No. 2) were run through the humidity tests outlined in MIL-STD-810C, Method 507, Procedure 1.

This test requires the test items to be exposed to 149 deg F and a relative humidity of 95 percent. The temperature is gradually raised from ambient to 149 F. This temperature is maintained for not less than six hours. The relative humidity is maintained at not less than 85 percent while the temperature is reduced in 16 hours to 86 F. These steps are repeated for a total of 10 cycles for not less than 240 hours. The two 36- $\times$  36-inch panels were examined at the conclusion of the test, and both had several small corner and edge delamination areas not exceeding 1/2 $\times$  1 inch. The panels otherwise exhibited good appearance.

Light transmission and haze readings taken on the panels before and after the humidity testing are shown in Table 2.

TABLE 2. HUMIDITY TEST DATA

	Before humidity tests	After test
Construction No. 1		
Light transmission average (percent)	72.3	72.0
Haze average (percent)	1.0	1.9
Construction No. 2		
Light transmission average (percent)	72.5	72.7
Haze average (percent)	1.0	1.8

e. Temperature Shock Testing

This test was run in accordance with MIL-STD-810C, Method 503, Procedure 1.

In this test, the armor composite is placed in an oven and heated to 160 deg F for not less than 4 hours or until the test item stabilizes. At the conclusion of this time, the transparent armor panel is transferred within 5 minutes to a cold chamber which has been stabilized at -40 deg F. This temperature was suggested by Goodyear Aerospace as the point where stress levels are at or near the maximum that a glass/plastic composite will tolerate. The panel is held at the low temperature for 4 hours or until stabilized and then returned to the +160 F chamber, where it is stabilized. The entire cycle is repeated two more times before the test is concluded.

The thermal shock test is the most severe test to which a glass/plastic composite is exposed.

During this test, two panels, 36 × 36 inches, were run through the complete cycle at -20 deg F, -40 deg F, and -60 deg F.

One panel construction, No. 1, was as proposed by Goodyear Aerospace, and listed in Contract DAAG 46-76-C-0070. The other panel tested, Construction No. 2, had Goodyear Aerospace% F4X-1 silicone interlayer substituted for the polyurethane interlayer between the glass plies only.

Prior to the start of the testing program, analysis had indicated that the proposed configuration would probably survive exposure to low-temperature conditions. It was recognized, however, that the design analysis contained some simplifying assumptions that were empirical. As a result, the test program was recognized as being developmental, with some possibility of the need for some trial and error design corrections during the test program, as well as demonstration of feasibility of the final design. **This** proved to be true, with cracking of the glass faces at lower temperatures a serious problem despite the predictions of the mathematical portion of the analysis.

Examination of the early test results indicated that the problem related to rate of change in temperature (thermal shock) rather than to stresses at stabilized conditions. The mathematical analysis at present does not include thermal strains caused by temperature transient conditions in the glass faces. This condition becomes increasingly serious as the thickness of the glass increases. All previous test verifications of the mathematical analysis had been made on configurations with glass faces of 3/8-inch or less (usually nearer 1/4-inch). It was deduced from these observations that the two pieces of 3/8-inch glass bonded with urethane interlayer was effectively equivalent to a monolithic sheet of 3/4-inch thick glass. It was further deduced that if the two sheets of 3/8-inch-thick glass were bonded with a very low modulus silicone interlayer, it would effectively decouple the two pieces of glass so that they would react as two individual pieces of 3/8-inch-thick glass. This would place the

silicone interlayer into a bond line that would be effectively protected from humidity conditions by the impervious glass and permit use of the polyurethane interlayer in the less protected bond line between the polycarbonate and the glass. Thus, one more empirical hypothesis has been added to the design analysis.

That is, while configurations using thin glass faces are potentially subject to glass cracking from thermal strains induced by the polycarbonate backing, composites with glass faces of about 3/8 inch or greater are more greatly affected by thermal strains within the glass itself from thermal shock. The tests to date verify the validity of this conclusion.

The panel containing the urethane interlayer throughout had the outer glass ply crack after exposure at the -40 deg F thermal cycle.

The modified panel containing the silicone interlayer between the glass survived even at the -60 F temperature. All of the panels passed the -20 F cycle.

**f. Ultraviolet Stabilization Testing**

The accelerated exposure to ultraviolet radiant energy was run on two 12-in.  $\times$  12-in. panels of Construction No. 1.

Panel number one was placed in the Goodyear Aerospace test chamber. This chamber is 8  $\times$  36  $\times$  50 inches in size. The chamber bulb type, placement, and reflector correspond to that described in FTMS No. 506, Method 6024. The chamber, however, does not utilize a rotating turntable, circulating controlled hot air, or fog generating source.

Panel number two was placed on the Goodyear Aerospace outdoor rack, which faces south and is slanted 45 deg off the horizontal.

The panels were examined and tested for light transmission and haze prior to test exposure and after 36 days (864 hours) and 345 days (8280 hours) of exposure. The results are shown in Table 3.

TABLE 3. ULTRAVIOLET RADIATION TEST DATA

Panel no.	Light transmission (average percent)			Haze (average percent)		
	Original	After 864 hr	After 8280 hr	Original	After 864 hr	After 8280 hr
1 (accelerated exposure)	72.0	72.2	72.4	2.4	3.6	3.4
2 (outdoor exposure)	72.1	72.2	72.4	2.4	3.1	3.8

g. Conclusion

This testing program has shown that glass/plastic composites can be produced which will pass high temperature, low temperature, thermal shock, humidity, and ultraviolet stabilization tests. The program has also indicated there is a very critical balance that must be maintained when designing composites and selecting the materials to be used.

There is evidence that panels exposed to high humidity for extended periods and then exposed to extreme thermal shock may show signs of delamination and some glass breakage. In this regard, it is difficult to visualize a situation where a helicopter or other low-flying aircraft would encounter both of these conditions in the short time as specified by MIL-STD-810C. It is recognized that **MIL-STD** testing imposes severe conditions to accelerate natural exposure effects.

Contract DAAG 46-76-C-0070 outlines a field testing program which will evaluate glass/plastic UH-1 windshields under actual conditions in two entirely different environments (Ft. Rucker, Alabama, and Yuma, Arizona). This testing is needed to establish a realistic test program for future programs involving glass/plastic composites. This field testing will run for approximately one year, and test results will be available by late 1978.

#### 4. FABRICATION AND OPTICAL EVALUATION

##### a. General

Three shipsets of UH-1 transparent armored windshields, P/N 3149000-100, were fabricated. The windshields were complete with all framing necessary for direct attachment to the existing fuselage. Except for relocation of the free air temperature gauge, use of longer windshield attachment screws, and an extension of the present windshield wiper bushing, the armored windshields can be directly substituted for the current standard acrylic windshields.

##### b. Refined Glass Forming Procedures

Because of the large variations in glass contours experienced in the previous contract, Goodyear Aerospace fabricated new tooling and formed all glass to more closely controlled tolerances. This simplified the mating of the glass and the plastic backing and enhanced the overall optical quality of the windshields.

##### c. Interlayer Improvement Evaluation

The urethane and silicone interlayer testing continued to define which of several casting procedures were most applicable and offered the best product reliability. Because of this effort, it was determined that several of the windshields produced would utilize the silicone interlayer between the plastic and the glass as well as between the two glass plies. This will afford the

opportunity to field test each interlayer system to determine if one type has any advantages over the other.

d. Design Analysis Approach

In addition to the design analysis of the windshield composites already discussed, a new structural investigation of the windshield framing and fuselage mount area was undertaken. The investigation was conducted to analytically verify the structural adequacy of the transparent armor installation. Supplemental report CLA-2168 covers this investigation in detail but was considered too lengthy for incorporation in this report.

To **summarize**, it was concluded that no structural problems are caused by the armored windshield installation. Because the armored windshields are much more rigid than the standard acrylic windshields, the armored parts aid in stabilizing the helicopter frame structure. The aircraft, with relocation of the battery to the aft position, stays within the allowable center of gravity **limits** established for the aircraft.

The transparent armor windshields weigh 99 pounds each, while the original Plexiglas windshields weigh 10 pounds each. Total weight increase per **shipset** resulting from the installation of the armored windshields was therefore 178 pounds.

e. Fabrication of Test Windshields

Three sets of windshields were fabricated as direct replacement articles for the UH-1 aircraft. The constructions shown in Figure 2 were selected because they offer the ballistic protection specified by the Army.

f. Optical Test Evaluation

All windshields produced were measured for thickness in nine locations to verify that an acceptable tolerance was held which would permit acceptable optics to be achieved (see Figures 3, 4, and 5).

Optical deviation measurements were taken in accordance with MIL-G-5485C, Paragraph 4.5.2.1 (see Tables 4 and 5).

Optical distortion evaluation was accomplished in accordance with MIL-G-5485C, Paragraph 4.5.3 (single- and double-exposure photographs). A data summary of the windshield optical properties, including distortion measurements, is presented in Table 5. Windshield photographs are shown in Figures 6 through 18. In addition, each set of windshields was mounted on a frame simulating the UH-1 mounting, and photographs were taken outdoors to demonstrate the optical quality (see Figures 19, 20, and 21).

The optical quality was considered very good for composites of this thickness and curvature.

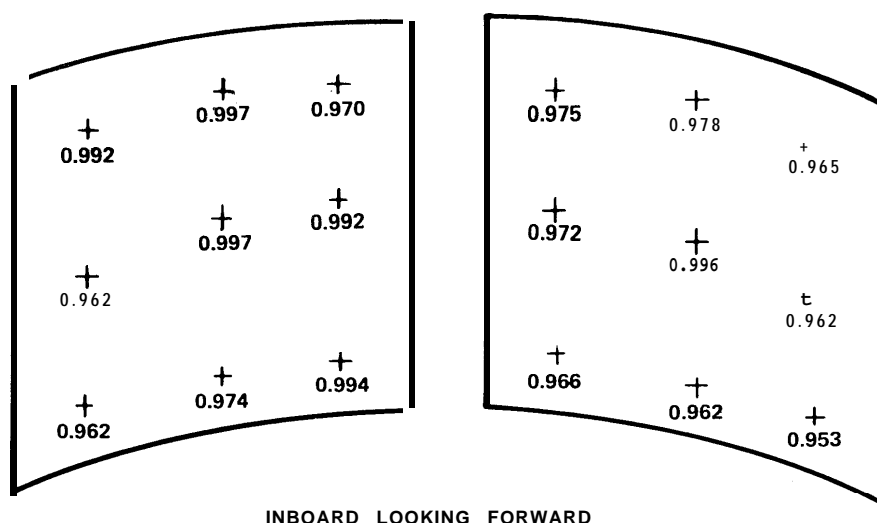


Figure 3. UH-1 Windshield Thickness Measurements - Windshield Set No. 1

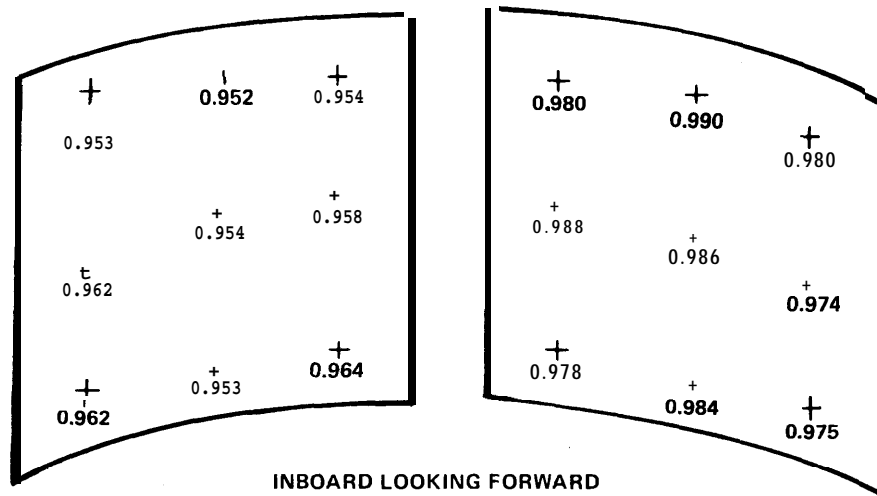


Figure 4. UH-1 Windshield Thickness Measurements - Windshield Set No. 2

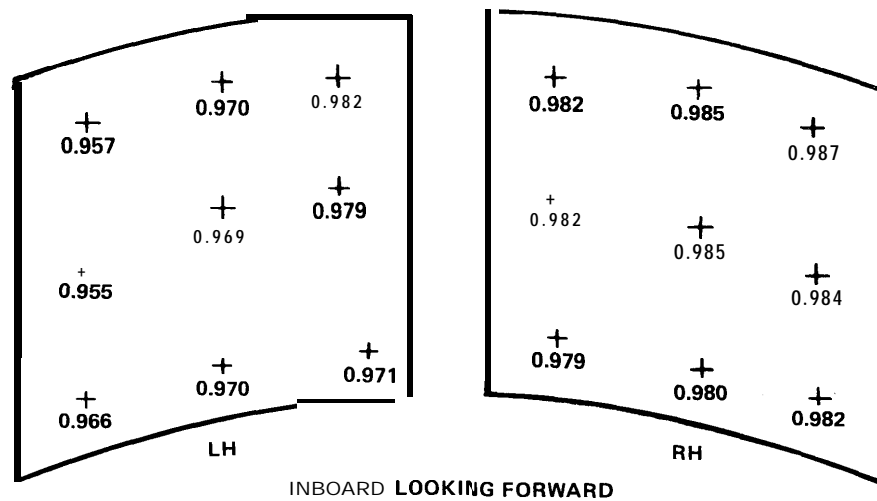
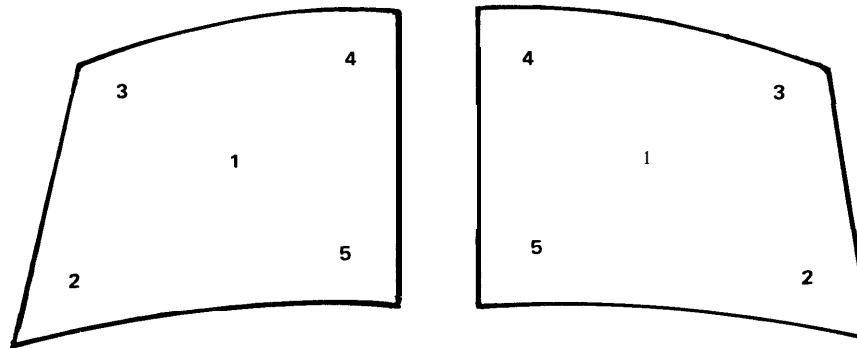


Figure 5. UH-1 Windshield Thickness Measurements - Windshield Set No. 3

TABLE 4. UH-1 TRANSPARENT ARMOR OPTICAL TEST DATA

Panel serial no.	Optical deviation (minutes)				
	Original measuring position*				
	1	2	3	4	5
1 RH	4	6.5	1	1	2
1 LH	2	3.5	3.5	5	2
2 RH	3	3	3	4	5
2 LH	2	1	2	3	1
3 RH	2	2	3	3	2
3 LH	2	3	2	3	2



\*Location of measuring position;s for optical deviation are shown in the sketch.

TABLE 5. UH-1 GLASS/PLASTIC ARMOR WINDSHIELDS OPTICAL TEST EVALUATION

Panel no.	Light transmission (percent average)	Haze (percent average)	Optical deviation (minutes average)	Optical distortion (slope)
1 RH	81.0	1.3	2.9	Slope 1 in 8 lower RH corner
1 LH	80.5	0.9	3.2	Slope 1 in 8 lower LH corner
2 RH	81.4	0.7	3.6	Slope 1 in 16 lower RH corner
2 LH	80.6	0.9	1.8	Slope 1 in 12 lower LH corner
3 RH	81.0	1.5	2.4	Slope 1 in 16 lower RH corner
3 LH	81.1	1.3	2.4	No significant slope

Light transmission — in accordance with Federal Test Method Standard 406, Method 3022.

Haze — in accordance with Federal Test Method Standard 406, Method 3022.

Optical deviation — MIL-G-5485C, Paragraph 4.5.2.1.

Optical distortion — in accordance with MIL-G-5485C, Paragraph 4.5.3 (double-exposure photograph).



Figure 6. Single-Exposure Photograph, Windshield S/N 1 (LH)

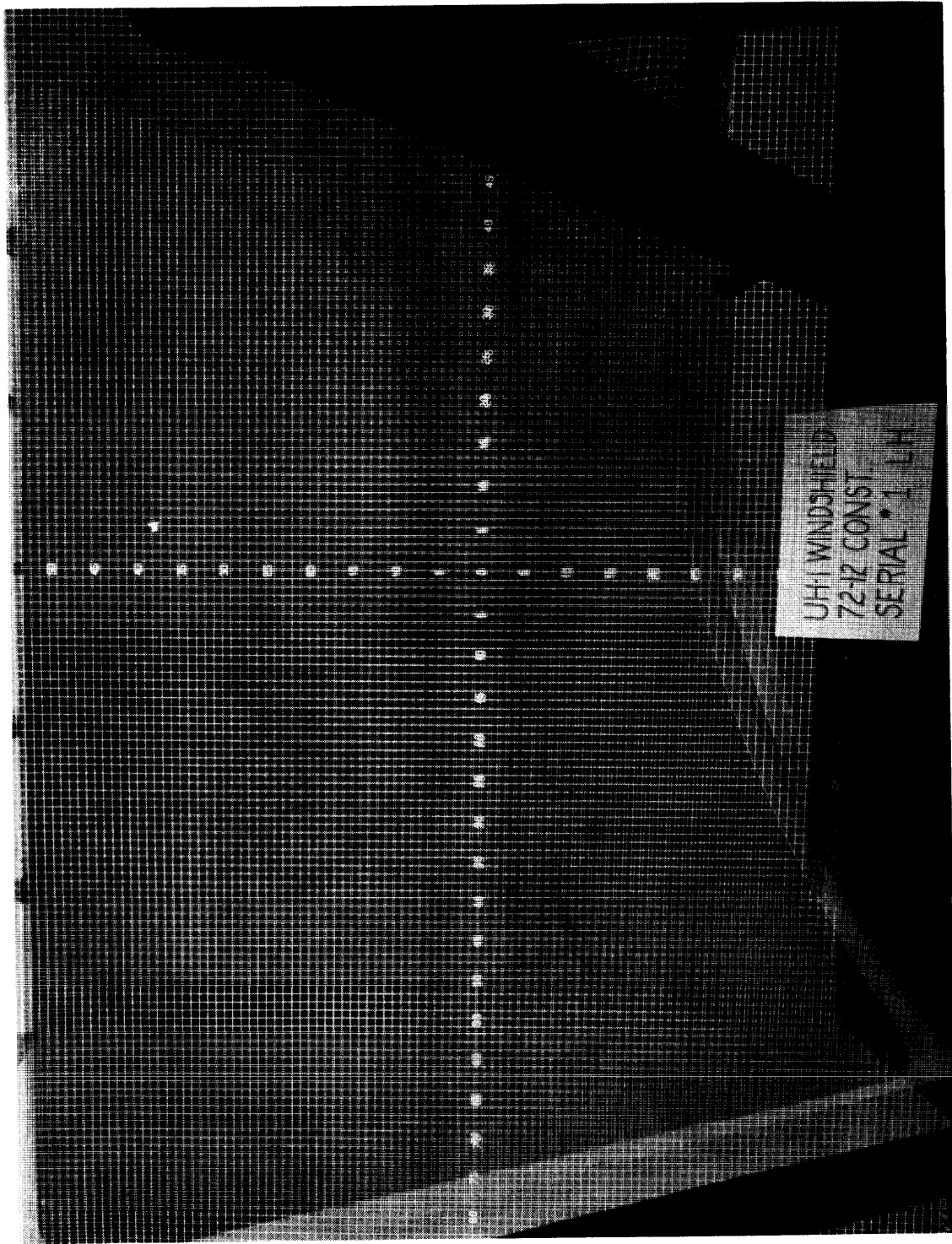


Figure 7. Double-Exposure Photograph, Windshield S/N 1 (LH)

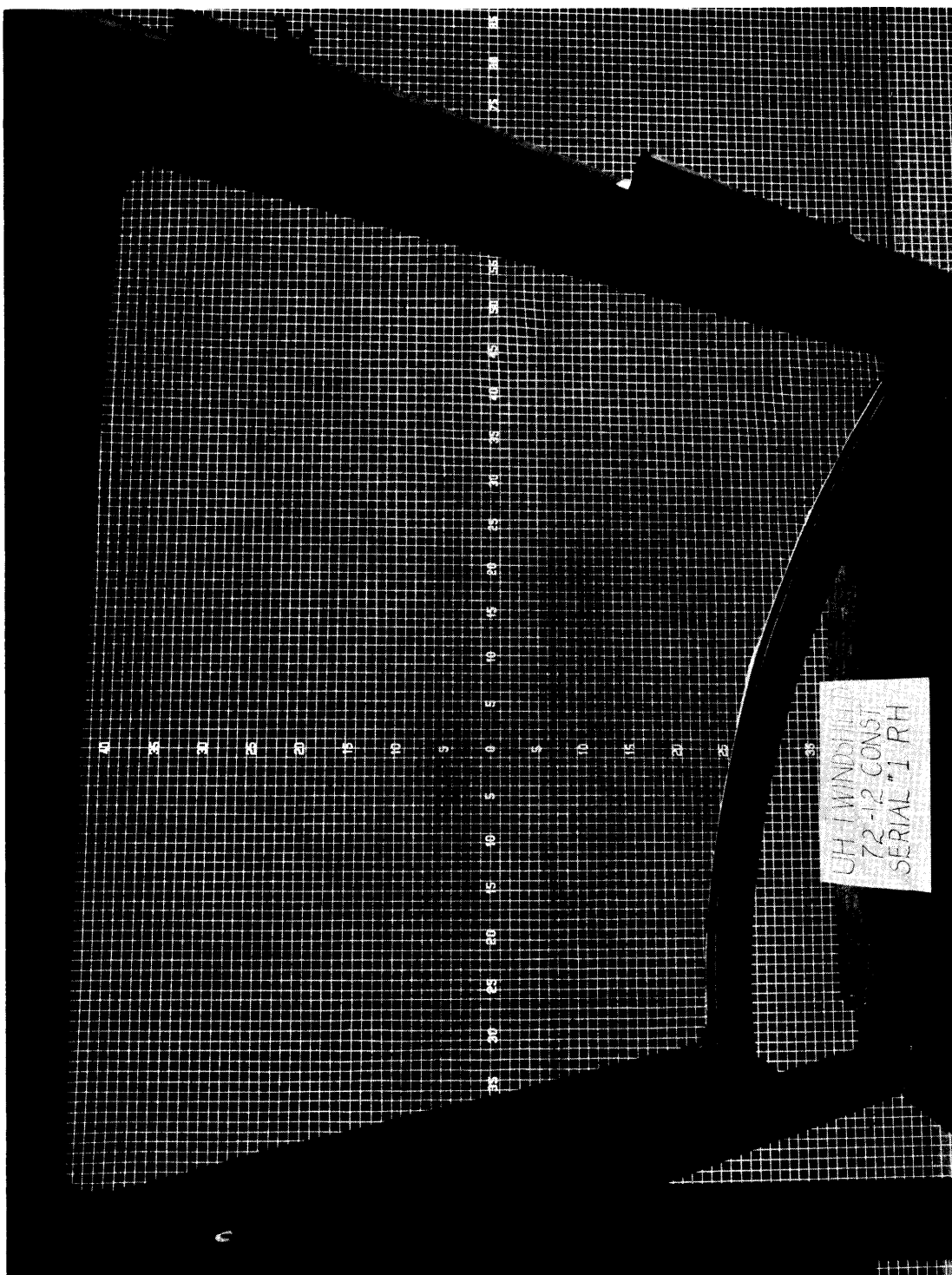


Figure 8 Single-Exposure Photograph Windshield S/N (RH)

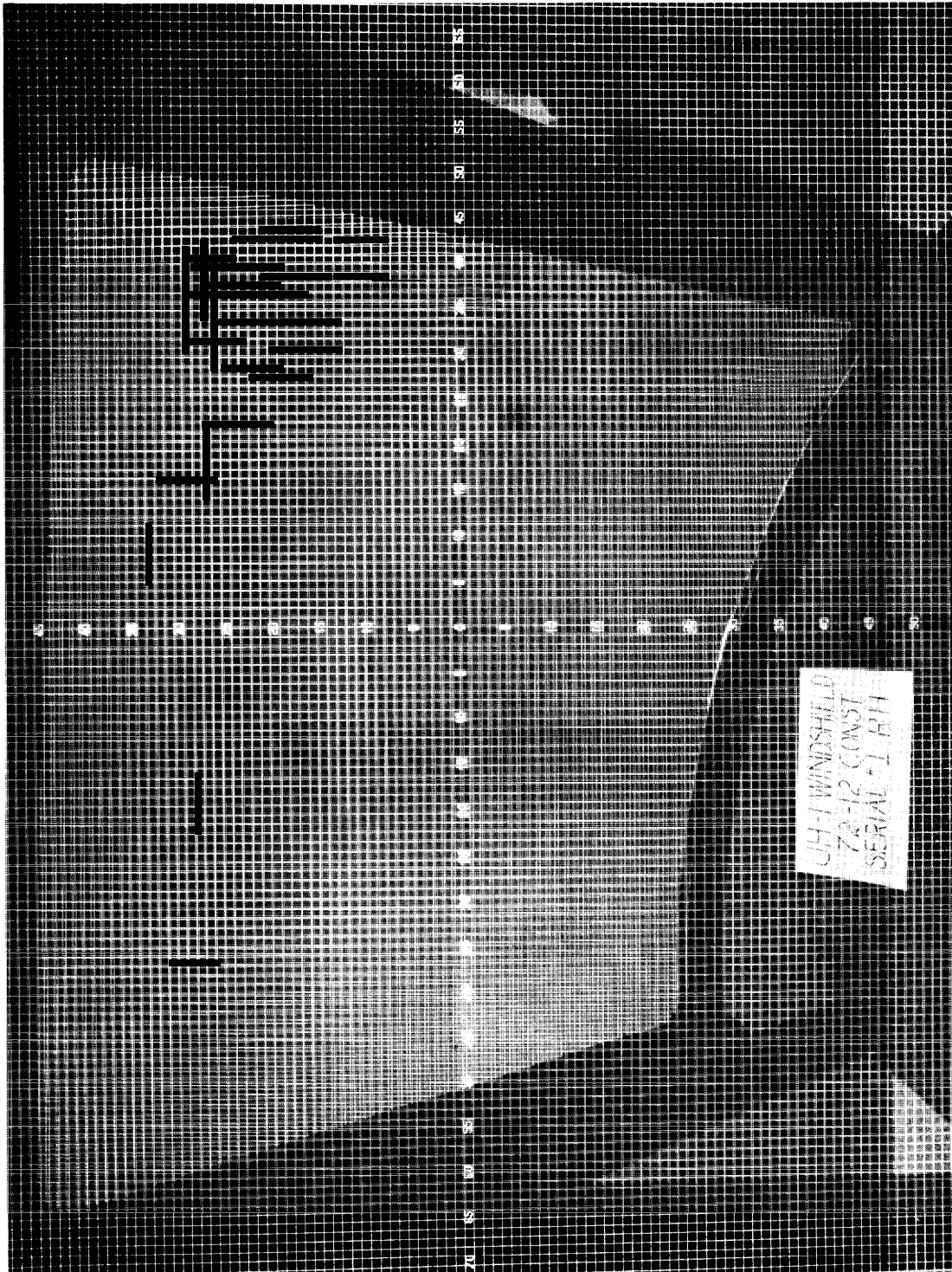


Figure 9. Double-Exposure Photograph, Windshield S/N 1 (RH)

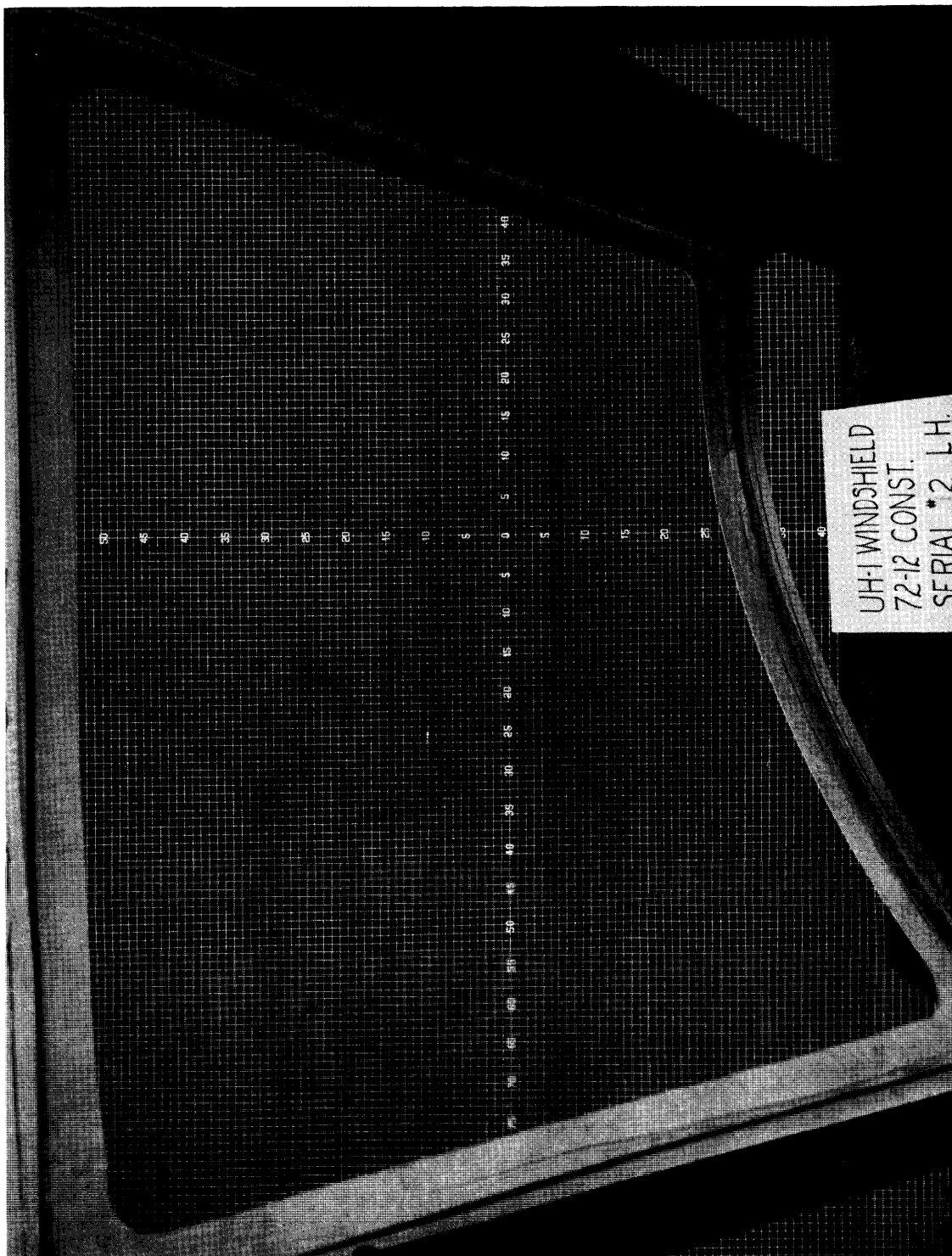


Figure 10. Single-Exposure Photograph, Windshield S/N 2 (LH)

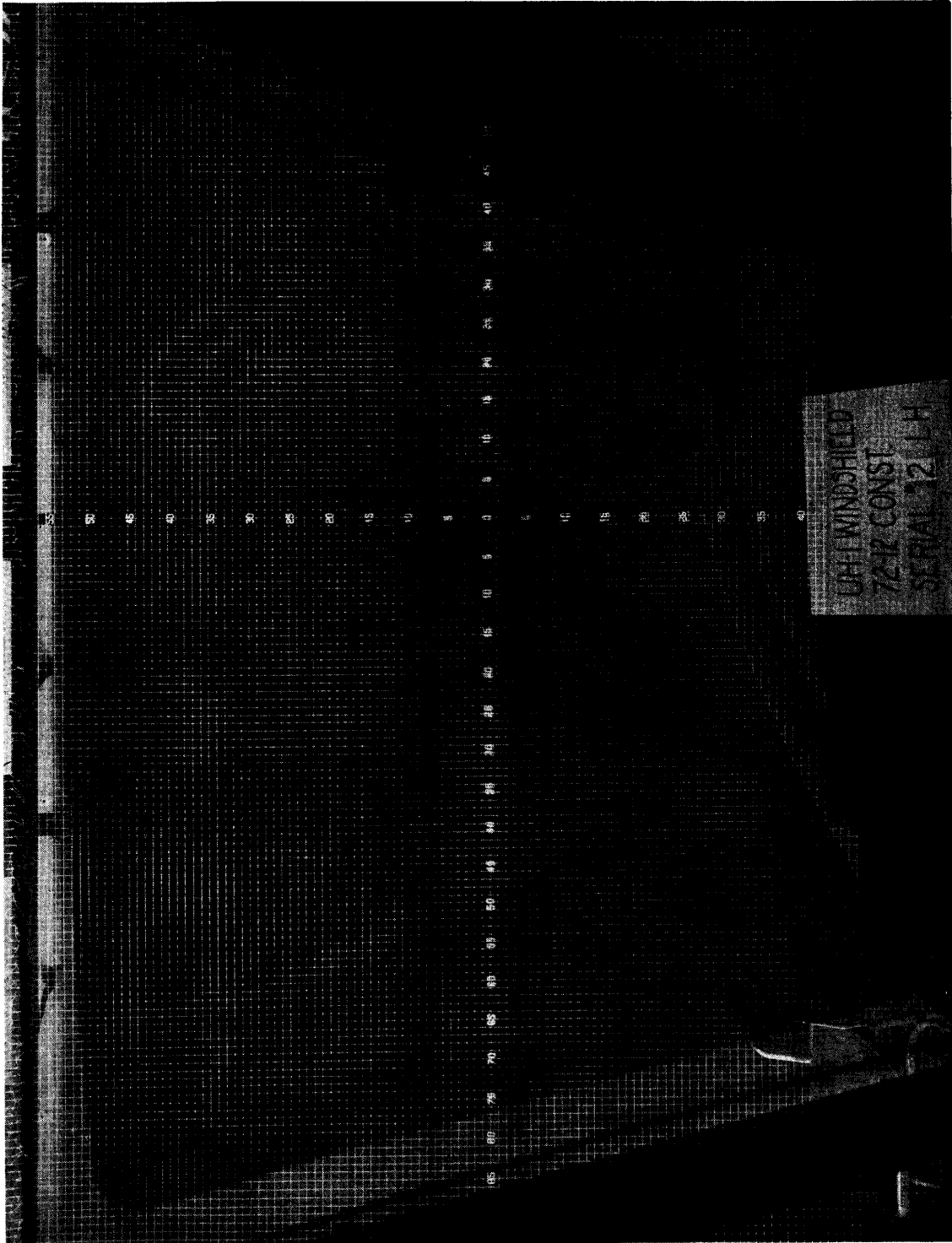


Figure 11. Double-Exposure Photograph, Windshield S/N 2 (LH)

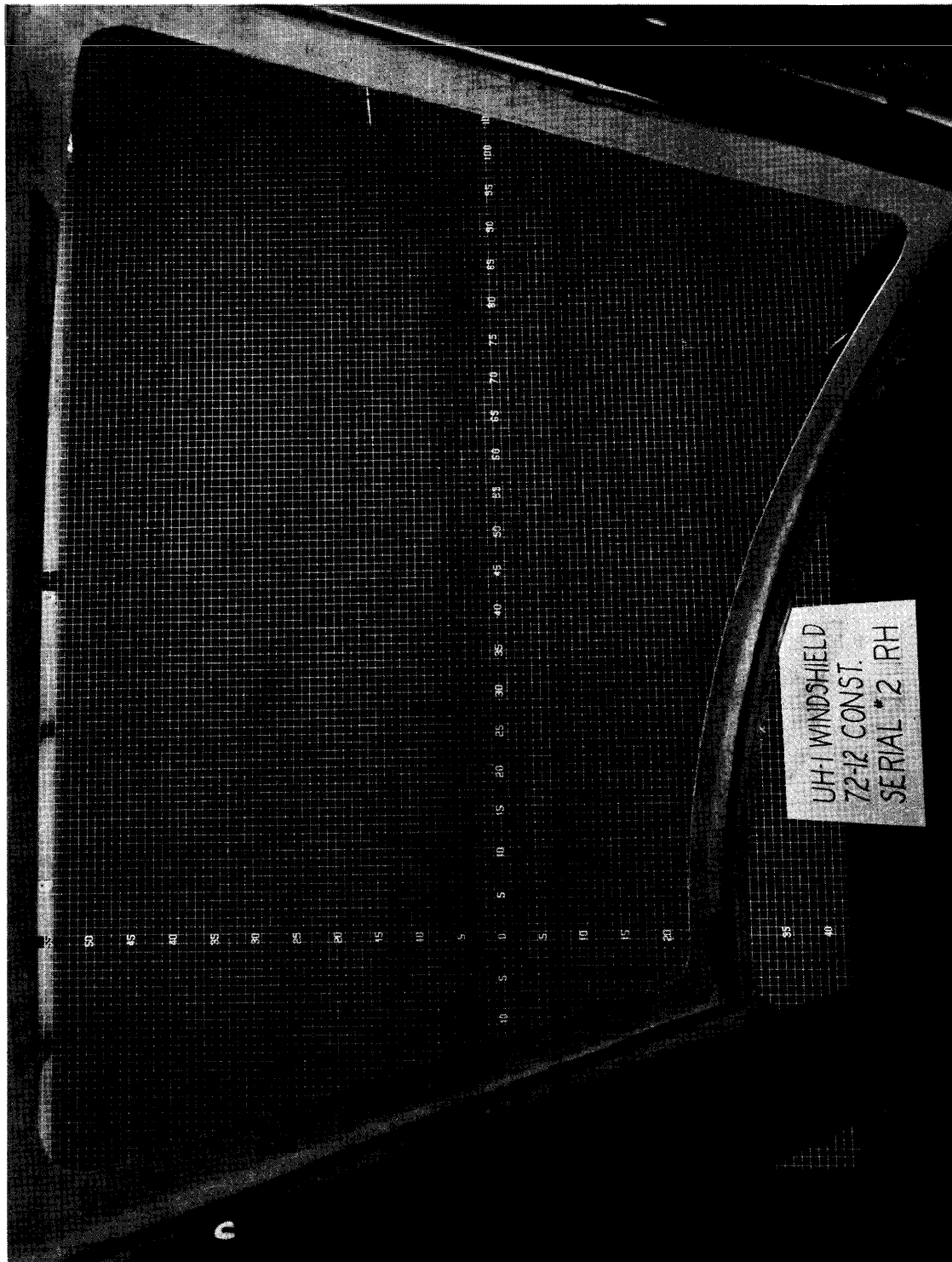


Figure 12. Single-Exposure Photograph, Windshield S/N 2 (RH)

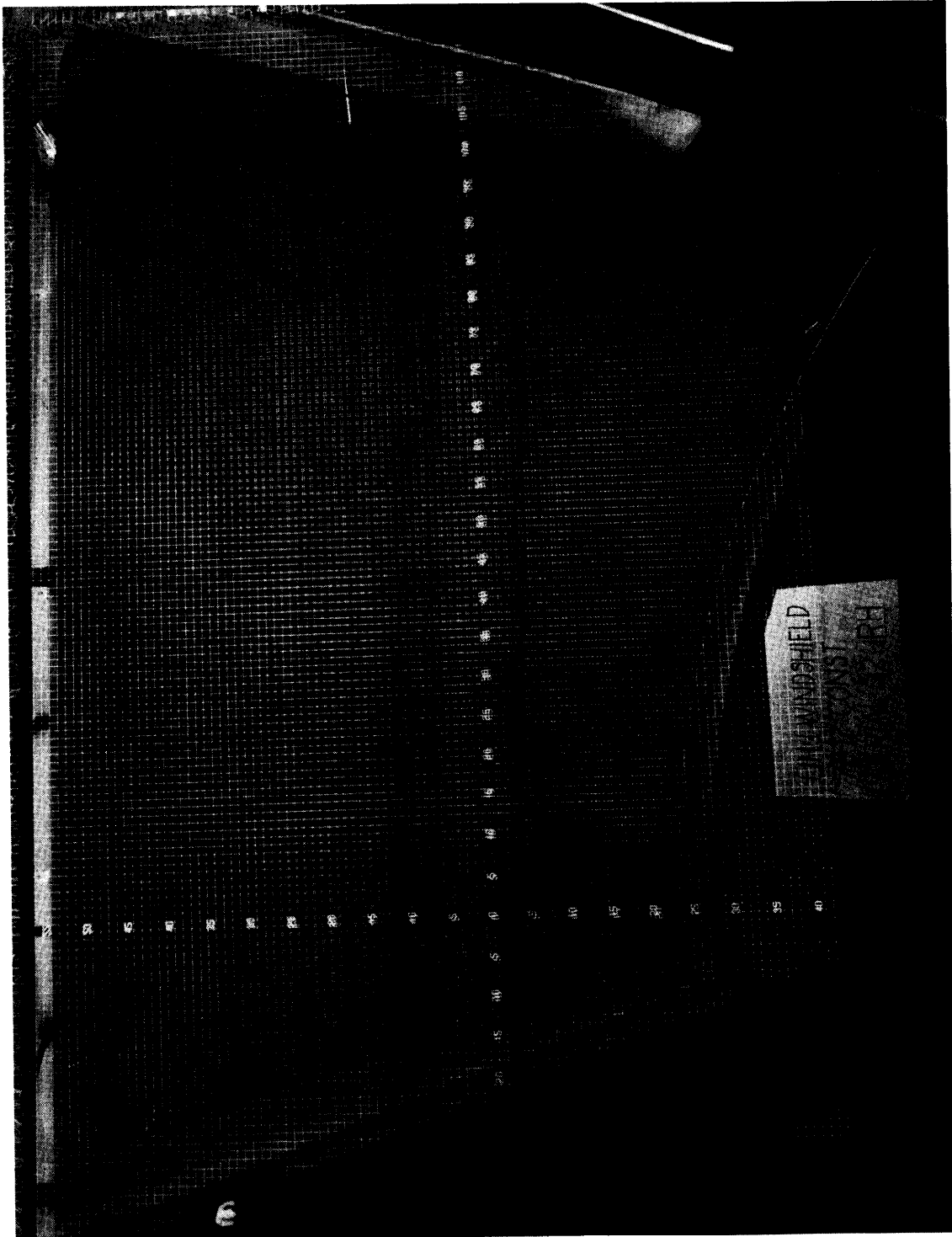


Figure 13. Double-Exposure Photograph, Windshield S/N 2 (RH)

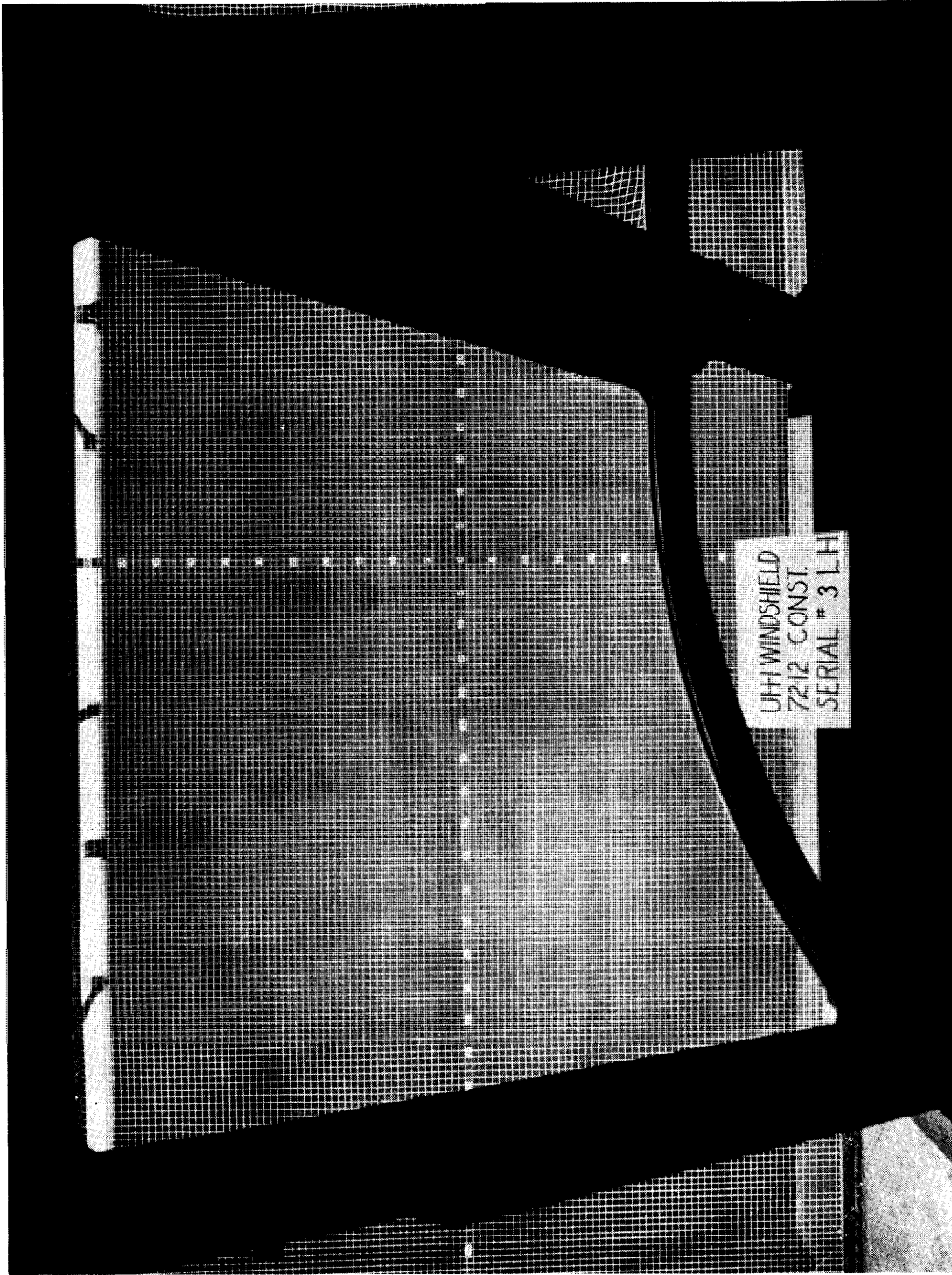


Figure 14. Single-Exposure Photograph, Windshield S/N 3 (LH)

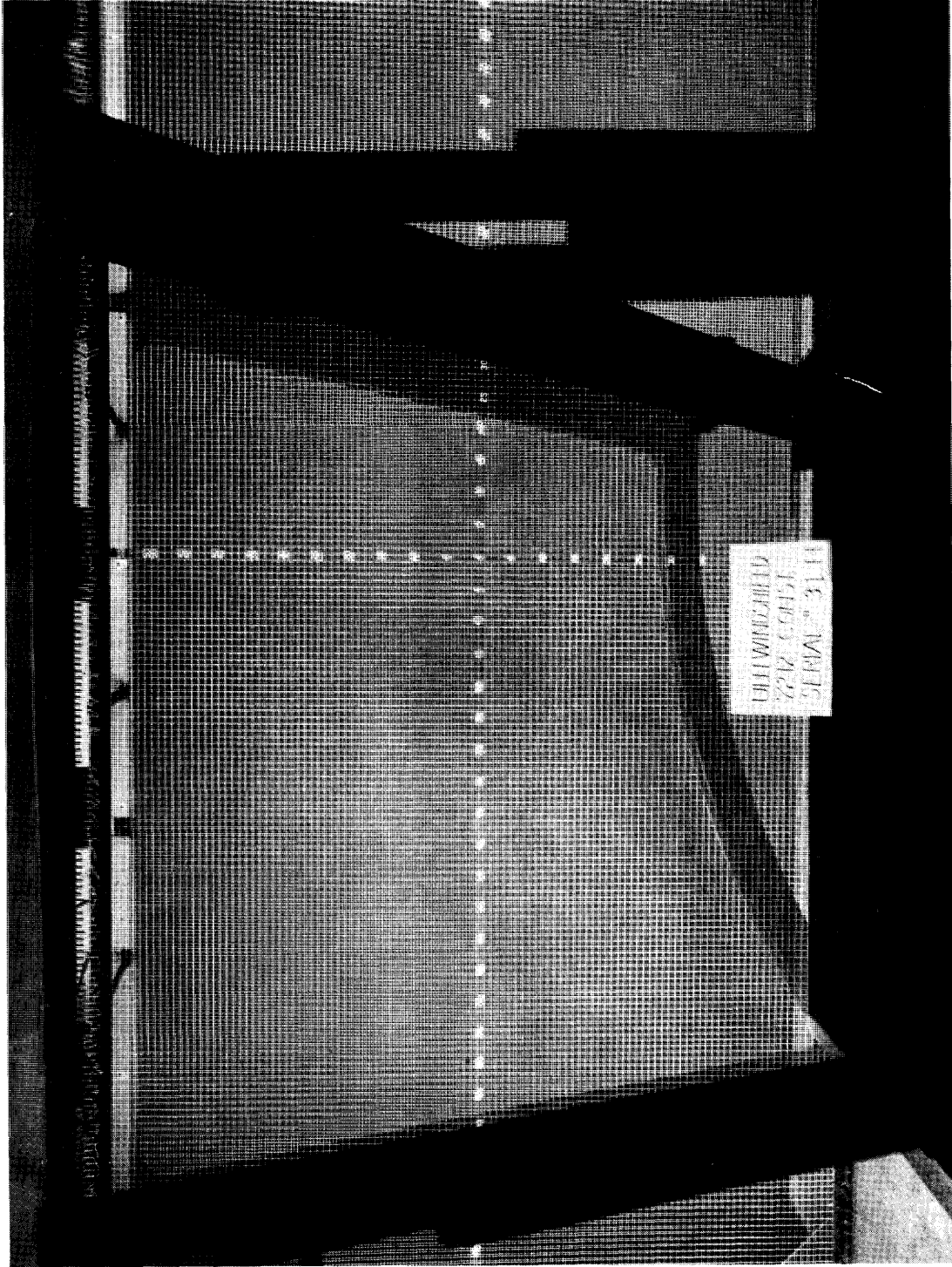


Figure 15. Double-Exposure Photograph, Windshield S/N 3 (LH)

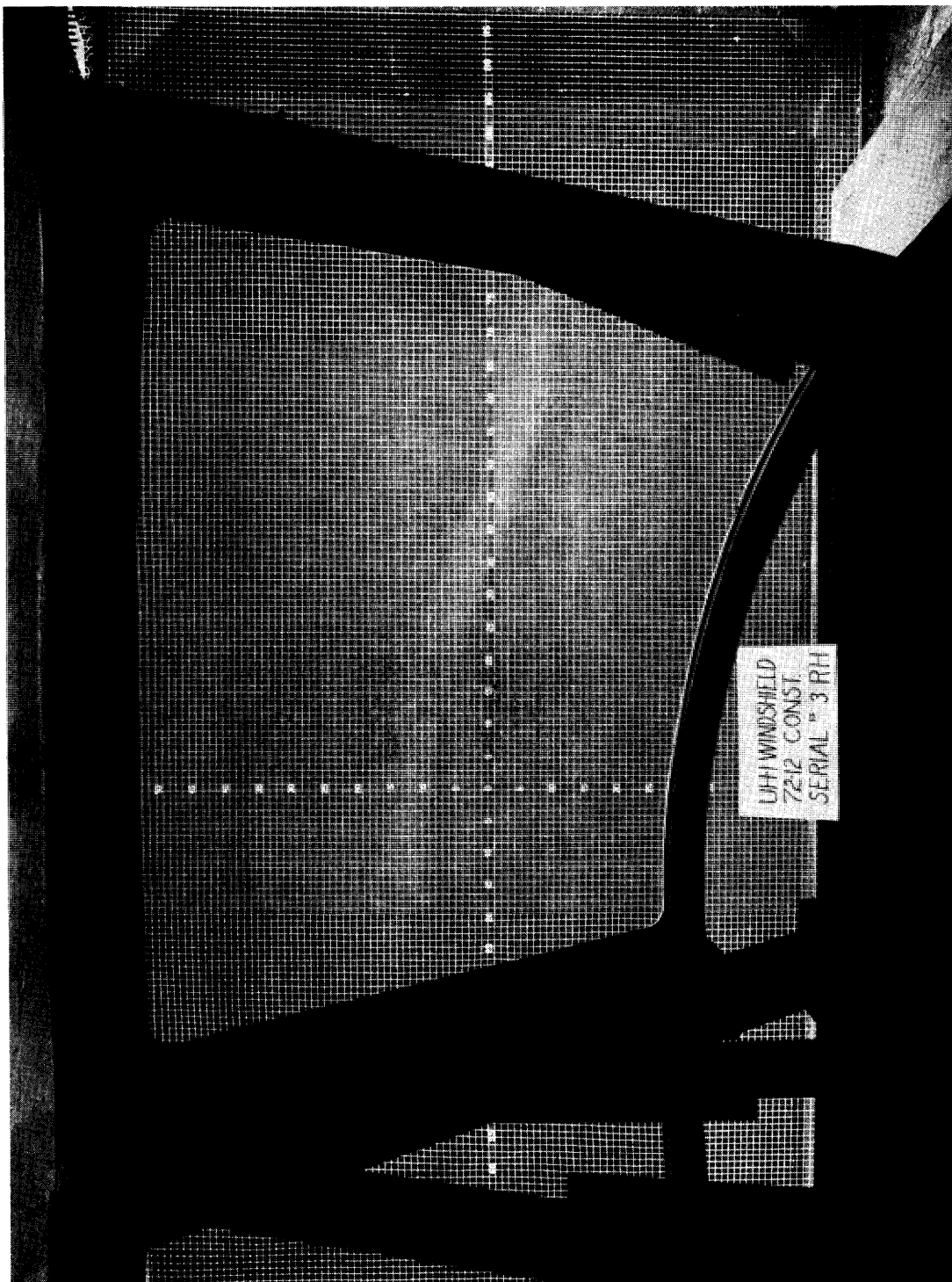


Figure 16. Single-Exposure Photograph, Windshield S/N 3 (RH)

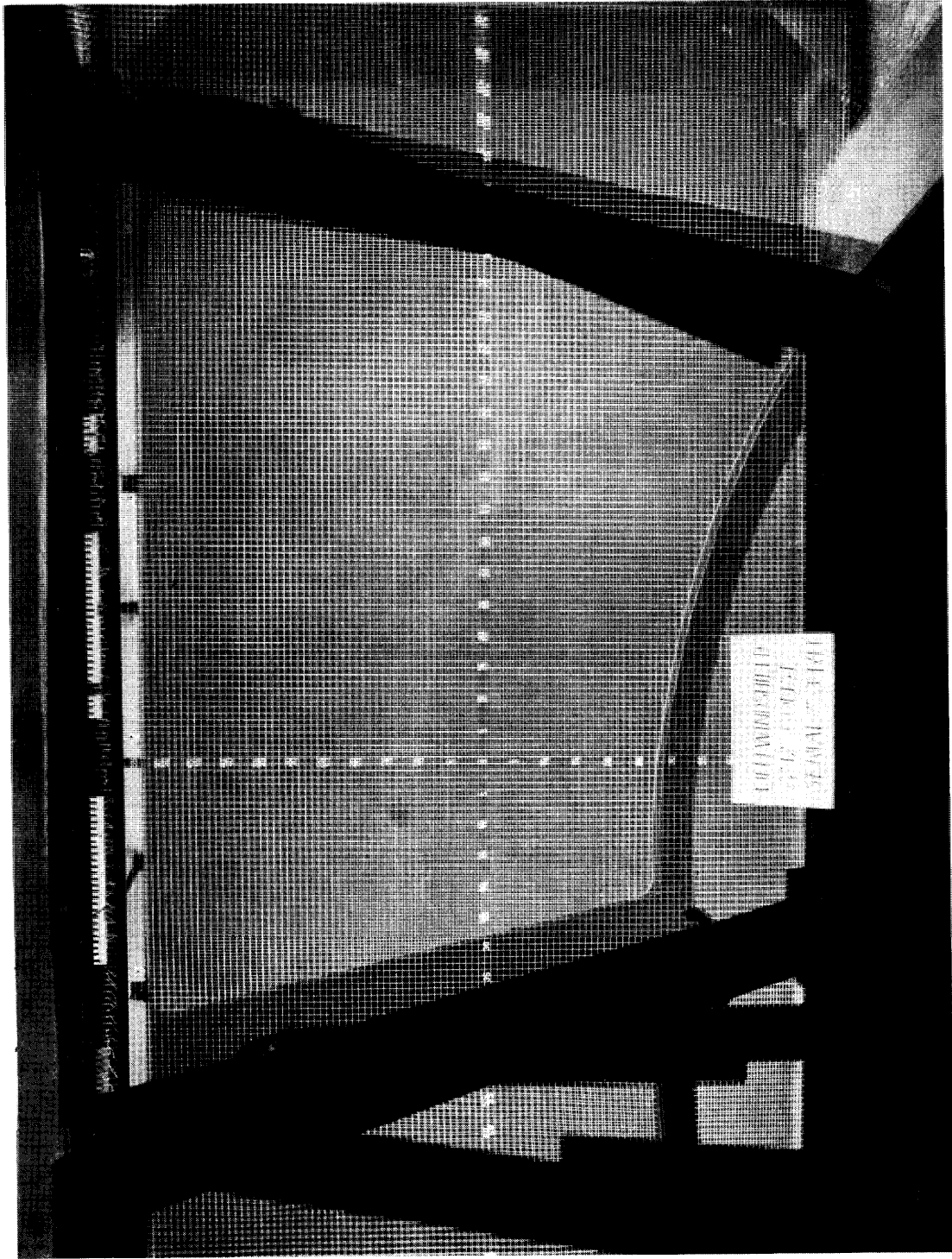


Figure 17. Double-Exposure Photograph, Windshield S/N 3 (RH)



Figure 18. Single-Exposure Photograph, Windshield Set S/N 3

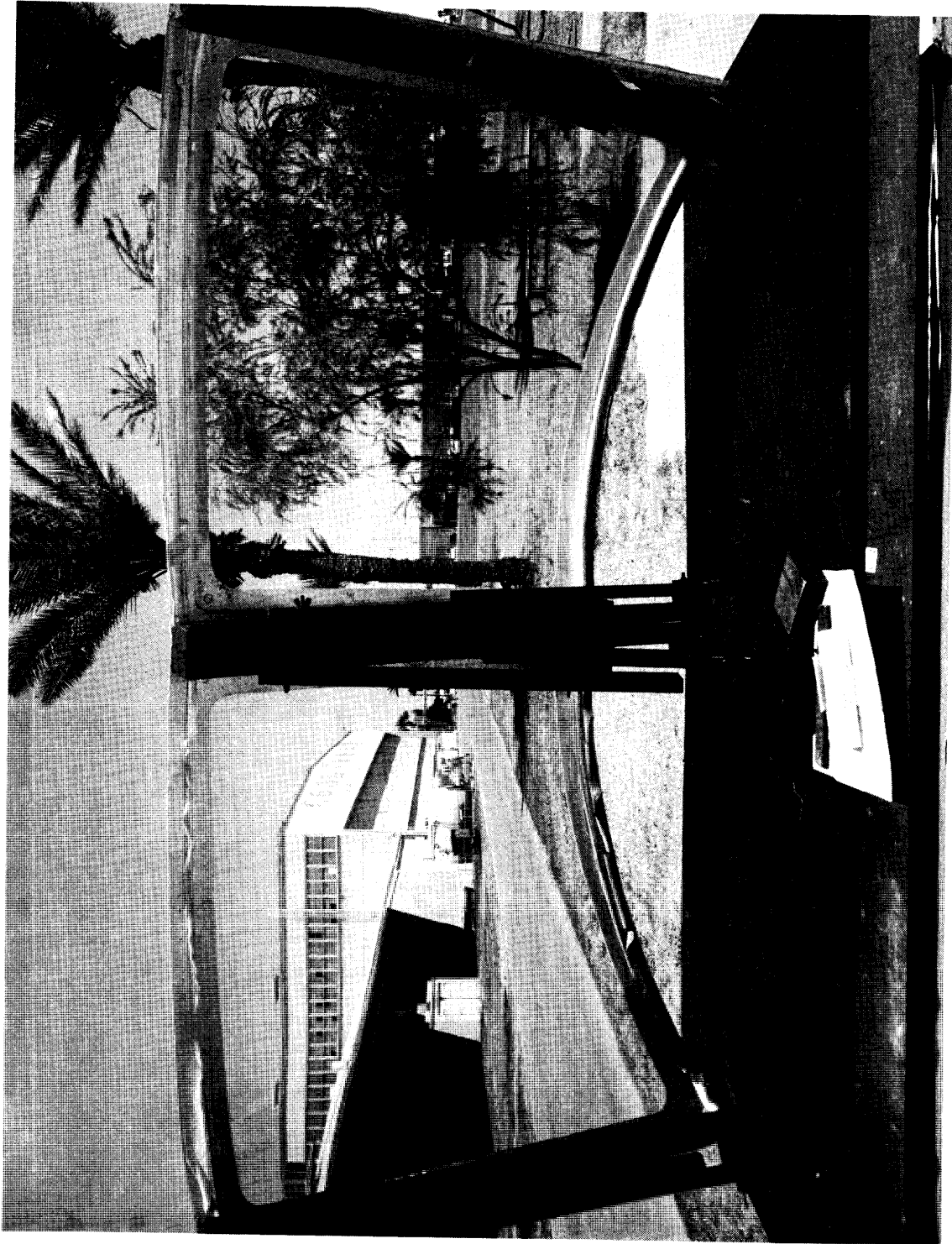


Figure 19. Inside Viewing of Windshield Set S/N 1

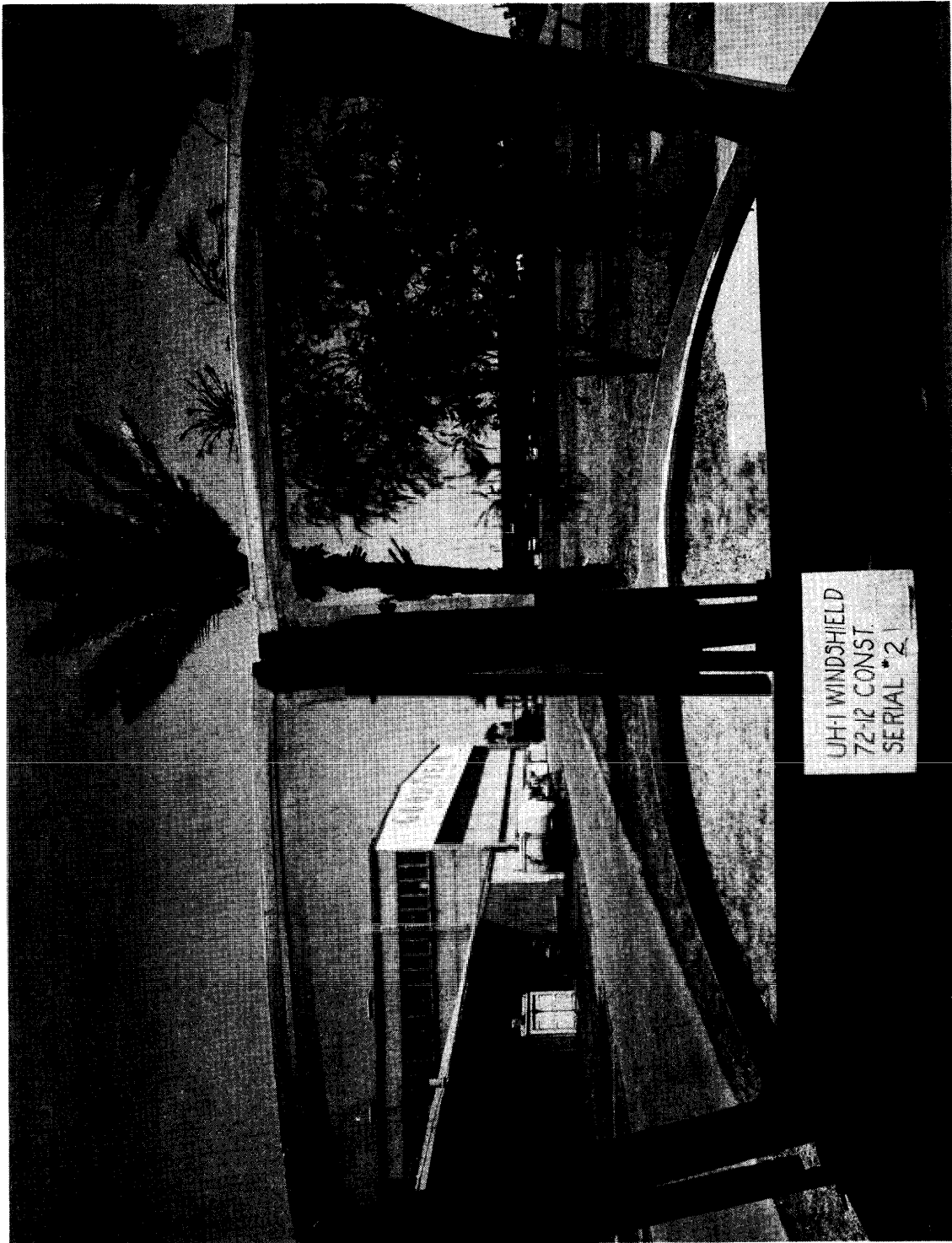


Figure 20. Inside Viewing of Windshield Set S/N 2

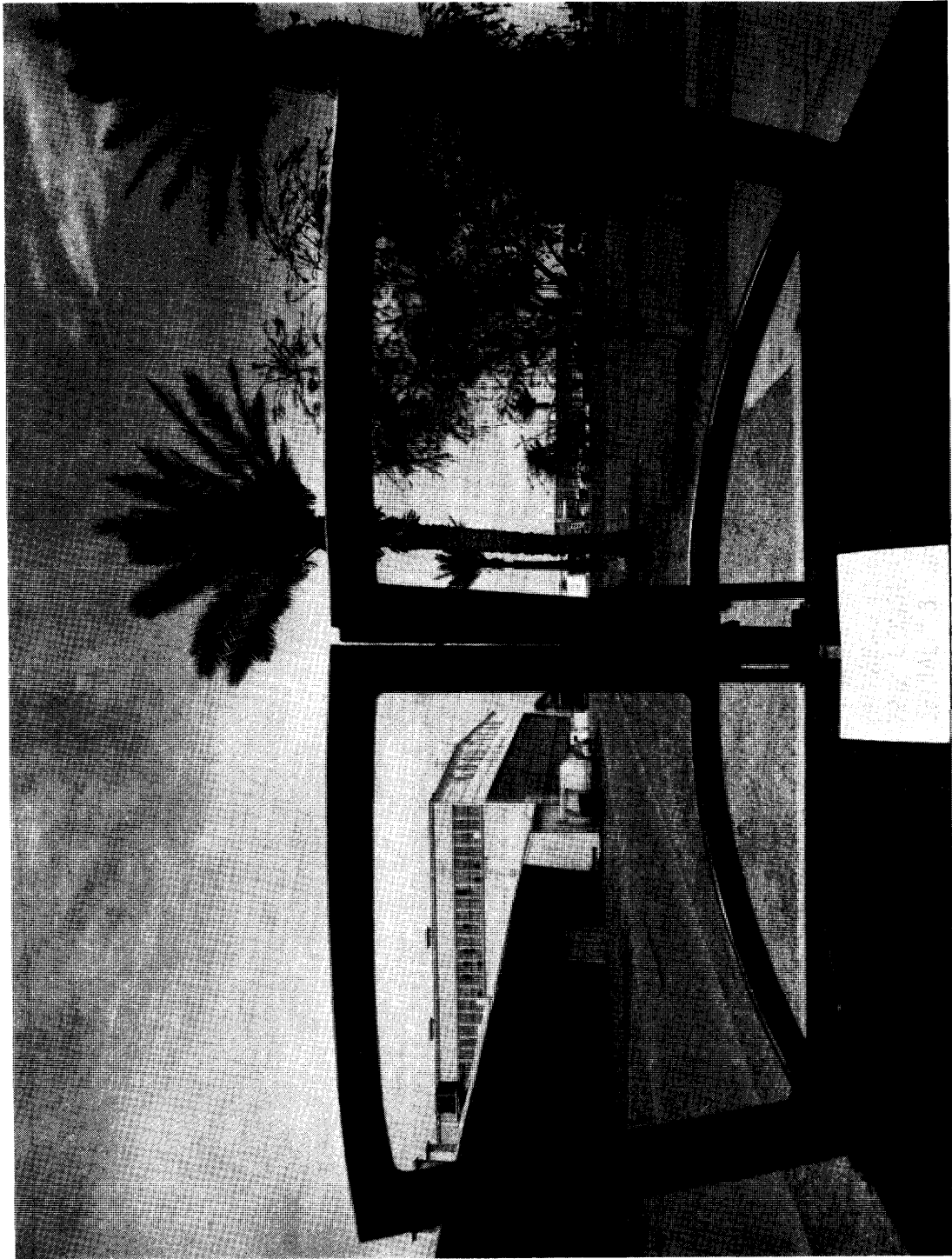


Figure 2 Inside Viewing of Windshield S S/N 3

## SECTION 3

### PHASE II FLIGHT TEST EVALUATION

#### 1. GENERAL

With the completion of the three sets of armored windshields, P/N 3149000-100, each part was inspected and bought off by representatives of the Army.

**Shipset** number one was installed in a helicopter fuselage located at Goodyear Aerospace, Litchfield Park, Arizona in September 1977. These parts are facing south and will be monitored periodically for resistance to the severe temperature and ultraviolet radiation exposure experienced in this desert area.

**Shipset** number two was delivered to the test airfield at Fort Rucker, Alabama, where the windshields were installed in August 1977 on a UH-1 aircraft being used on various flight test programs. The rather wet and humid conditions experienced in this area should complement the testing conducted at the two other locations to provide the weather extremes experienced in most areas of the world.

**Shipset** number three was delivered to the U. S. Army Proving Ground (YPG), Laguna Field, Yuma, Arizona, and installed in June 1977 on a helicopter. These armored windshields will be exposed to the hot climate conditions of that area and will be evaluated by various pilots assigned to fly the aircraft on numerous missions. The flight test evaluation at both test facilities is scheduled over a six-month period.

#### 2. INSTALLATION OF TEST ARTICLES

The installation of the windshields at the Yuma Proving Grounds showed the armored types can be installed as a direct replacement of the standard units. Modification of the windshield wiper arm to accommodate the greater part thickness and relocation of the free air temperature gage are the only modifications

that should be required if production lots of windshields are ordered in the future. Improved tooling for manufacture will overcome the contour variations experienced during the installation.

### **3. FLIGHT TEST EVALUATION**

After the armored windshields were installed, the weight and balance of the ship was checked and found to be within acceptable limits with the battery located in its aft position.

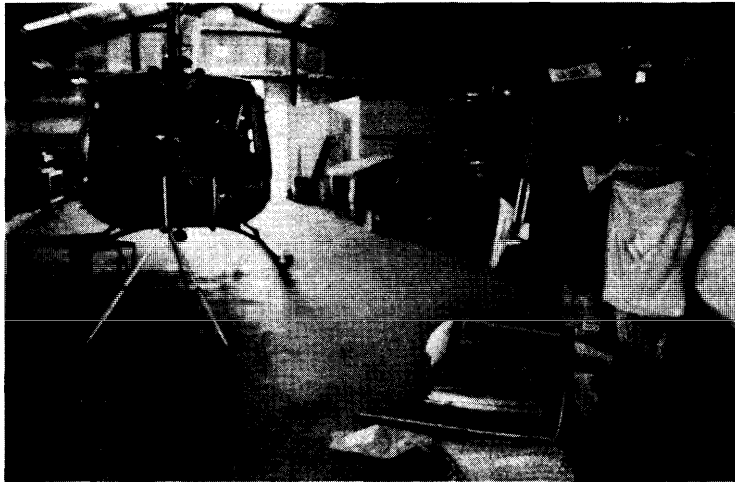
The first flight test was made at Yuma on June 29, 1977. The optical quality was reported by the pilot to be very good, and no adverse comments were offered. These flights are scheduled to continue for a minimum of six months with each pilot reporting his observations.

Flight test forms will be filled out by each pilot flying the aircraft.

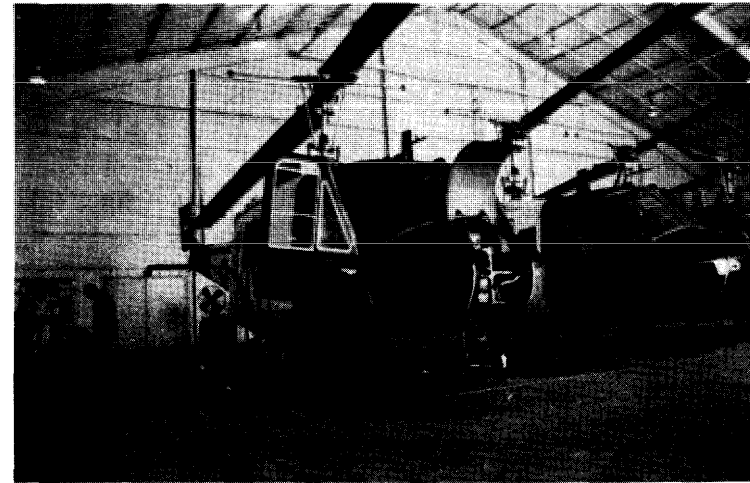
Figure 22 shows the steps of installation, balancing, and flight test recorded at the U. S. Army Proving Ground, Laguna Field, Yuma, Arizona.

### **4. REPORTS**

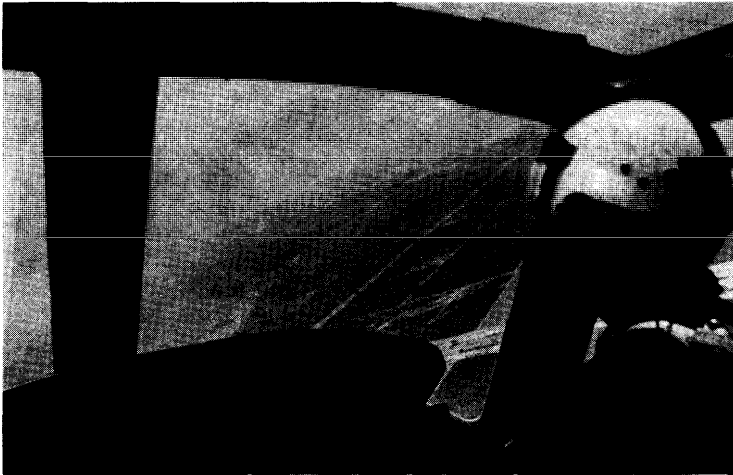
Personnel at both Yuma and Fort Rucker have been assigned to monitor the condition of the windshields and report pilot comments during the flight test program. These reports will be transmitted to Mr. Gordon Parsons, AMXMR-ER Technical Supervisor, Army Materials and Mechanics Research Center, Watertown, Massachusetts.



(1) Remove Standard Windshields and Replace with Armored Windshields



(2) Weigh and Balance Aircraft per TM55-405-9



(3) Optical Evaluation RH Armored Windshield during Flight Test at Yuma, Arizona



(4) Optical Evaluation LH Armored Windshield during Flight Test at Yuma, Arizona

Figure 22. Installation, Balancing, and Flight Test Procedure



## SECTION 4

### CONCLUSIONS AND RECOMMENDATIONS

#### 1. CONCLUSIONS

The conclusions resulting from this work are as follows:

1. Glass/plastic transparent armor installation can be designed and fabricated which will increase overall survivability by protecting the aircrew and vital components of the aircraft. The armor is capable of defeating projectiles and fragments without backside spalling of injurious particles. This unique combination of materials offers the low area1 density (armor weight per square foot) necessary for aircraft usage
2. Although it is now possible to offer curved transparent armored assemblies with good optical quality, flat armor panels should be considered wherever possible because of their lower cost and superior optical quality.

#### 2. RECOMMENDATIONS

The following recommendations are made as a result of work accomplished on this contract.

Redesign of the edge attachment should be made in the following manner to accommodate ship-to-ship variations in airframe and manufacturing tolerance associated with glass bending.

The polycarbonate layer of the composite should terminate at the edge of the glass. The Fiberglass edge attachment should be designed with sufficient strength to retain the glass/plastic windshield and mount it to the airframe. This design would

partially uncouple loads transmitted into the transparent composite when bolting the assembly to the airframe.

The possibility of incorporating scaled protection level composites in the UH-1 and other aircraft should be studied as a weight savings effort.

A study should be conducted to demonstrate the feasibility of adding glass/plastic transparent armor on newer-inventory Army aircraft. After defining those aircraft which by mission requirements could most benefit by installation of such armor, a feasibility and prototype design study should be undertaken.

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